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Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

THE EFFECT OF HEATING RATES ON PRODUCTIVITY, COKE QUALITY AND COKING PRESSURES FROM CONVENTIONALLY AND PARTIALLY BRIQUETTED CHARGES CARBONIZED IN CANMET'S PILOT-SCALE COKE OVENS

J.T. Price and J.F. Gransden

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by

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ABSTRACT

A coal blend typical of that used by the Canadian steel industry was carbonized conventionally and partially briquetted at several heating rates in all four of CANMET's moveable wall test ovens. Partial briquetting 30% of the coal charged to the coke oven improved all coke quality parameters. Increased coking rates improved ASTM hardness, coke strength after reaction, and coke reactivities but caused coke stability to deteriorate and mean coke size to decrease for both conventional and partially briquetted charges. Results from all the CANMET test ovens indicated ASTM coke stability could be maintained at the same value as the conventional charge but with a 20 percent increase in coke productivity if charges were carbonized 30% partially briquetted at faster heating rates. All other coke quality parameters would improve. Coke oven wall pressures increased only slightly for partially briquetted charges carbonized in the 460-mm oven which uses industrial bulk densities. However, results from the other test ovens which use more rigorous conditions indicated excessive coking pressures might result for partially briquetted charges at some coke plants depending on oven construction and the maximum allowable wall pressure deemed safe for their operation.

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INTRODUCTION

The partial briquetting of coal charged to coke ovens is a technology used extensively in Japan to produce metallurgical coke by utilizing poorer quality coking coals. Two methods are used extensively by Japanese coke makers. The first involves briquetting 30% of a blend containing coking and non-coking coal, mixing the briquets with the remaining blend, and charging to the coke oven. The second method incorporates all non-coking coals into the briquets which are then mixed at a 30 weight percent proportion with good matrix coals. The former method is used by Nippon Kokan K.K. and Nippon Steel Corporation while the latter method is used at the Sumikin Coke Company (1-4 & 5-7).

Extensive partial briquetting investigations at CANMET have been reported for both good and poor coking coal blends (8,9,10). In one study coke oven wall pressures increased significantly when more than 30% of a good coking blend was briquetted. Consequently, for most CANMET partial briquetting investigations the amount of briquetted coal was restricted to 30%. Other investigations in CANMET's 460-mm wide pilot oven have shown that the use of partial briquetting technology will enable substantial quantities of nonand poor-coking materials to be added to binary high volatile (hv) low volatile (lv) blends without causing any deterioration to coke quality. Also, by partial briquetting some binary lv-hv blends, only 10% of lv coal is required to make metallurgical coke having the same strength as conventional charges containing 75% hv - 25% lv.

Partial briquetting tests using four Canadian steel companies reference blends showed that coke quality improved by 2.6 to 6.7 ASTM stability units from results for the conventional charges. Coking pressures were not excessive and oven productivities remained about the same for the partially briquetted charges although coking times were longer than for the conventional charges.

The object of this investigation was to determine the effects of increased coking rates on the productivity; coke quality and coking pressures of a typical Canadian steel company coking blend when carbonized conventionally and 30% partially briquetted. Could coke oven productivity be increased by carbonizing partially briquetted industrial charges at increased coking rates without deteriorating coke quality below that for conventional charges or causing excessive coke-oven wall pressures (greater than 14 kPa)?

In this investigation carbonization tests were made with one Canadian steel company's reference blend in all four CANMET test ovens. The 460-mm oven was used primarily to evaluate the effects of coking rate and oven productivity on coke quality of conventional and partially briquetted charges. The Koppers oven was used mainly to determine the effect of coking rate and oven productivity on coke oven wall pressures. Additional tests were run in the Ottawa 310-mm oven and the Edmonton 460-mm Carbolite oven for comparison purposes.

EXPERIMENTAL METHODS

Coal Properties

The coal used in this investigation was supplied by a Canadian steelmaker and is typical of that used by most of the major Canadian cokemakers. Properties are listed in Table 1.

Carbonization Procedures

Carbonization tests were conducted in all four of CANMET's moveable wall test ovens. Some construction details and standard operating conditions for each oven with conventional charges are listed in Table 2. For partially briquetted charges the matrix coal was prepared identically to that for conventional charging and was sampled for rheological and petrographic analyses. The coal blend for briquetting was pulverized nominally to 90% minus 1 mm, mixed with 6% PDA binder in a double-arm kneeder-mixer at 100°C and then briquetted in a roll press which produced pillow-shaped briquets 30 x 30 x 18 mm. Segregation of the loose coal from the briquets must be avoided during charging and matrix coal and briquets were layered into a charging hopper and dropped into the test oven (3,11,12). Briquet moisture at the time of charging was 1.2-1.8%. A flow diagram of CANMET's partial briquetting procedures is shown in Fig. 1.

Coking rates and coke oven productivities were altered in the pilot ovens by changing the flue temperature. Conventional and partially briquetted charges were carbonized at four flue temperatures of 1075, 1125, 1220, and 1275°C in the 460-mm oven and at temperatures of 1010, 1080, 1115, and 1175°C in the Koppers oven. Studies were also done in the 310-mm oven at two coking rates; the standard and slow coking rates were obtained by starting the tests

at flue temperatures of 900 and 815°C respectively and programming the flue temperatures to increase by 19°C/h. The conventionally and partially briquetted charges were carbonized in the Carbolite oven using the standard operating conditions, given in Table 2.

After carbonization, coke was removed from the oven, water quenched, dropped 3 m to simulate commercial coke handling, dried, screened, and tested for coke strength according to ASTM and JIS tumbler methods (13,14). Coke strength after reaction (CSR) tests were made on selected cokes (15).

STUDIES IN THE 460-MM OVEN

Oven Productivity

Results from the investigation of the effects of four flue temperatures (coking rates) on properties of coke made conventionally and partially briquetted are listed in Table 3. Dry coal bulk density in the oven was controlled near 780 kg/m^3 for all conventional charges while partially briquetted charges gave values 4.5% higher near 815 kg/m^3. The increase in coal bulk density of partially briquetted charges also resulted in mean coking times to 900°C about 4% longer than for the conventional charges for each of the four flue temperatures. Figure 2 indicates that coking times to 900°C (and hence coking rate) for both conventional and partially briquetted charges can be predicted equally well from a linear equation based on oven flue temperature and coal bulk density. Thus for a given flue temperature coke oven productivities are not expected to change significantly for conventional or partially briquetted charges as indicated in Fig. 3, based on:

$$\text{Oven coke productivity} = \frac{(\text{coal bulk density}) \times (\text{coke yield})}{(\text{coking time to } 900°\text{C})}$$

However, Fig. 3 also shows oven coke productivity (and coking rate) can be increased significantly for both conventional and partially briquetted charges by raising the flue temperature according to:

$$\text{Oven coke productivity} = 0.0614\text{FT} - 35.67,$$

where FT is flue temperatue.

Effect of oven productivity on coke quality for conventional and partially briquetted charges

The mean size of coke (MCS) decreased as flue temperatures (FT) were increased for both conventional and partially briquetted charges as indicated in Table 3 and the following regression equations:

MCS = 161.0 - 0.0896FT, r = 0.93 for conventional charges, and
MCS = 160.8 - 0.0881FT, r = 0.97 for partially briquetted charges.

The MCS for partially briquetted charges was approximately 1.5 - 1.7 mm smaller than that from the conventional charges.

Table 3 shows ASTM stabilities of partially briquetted charges were about 5 units higher than the conventional charges as was found earlier and decreased as flue temperatures were increased (10). Linear regression shows some relationship exists between the MCS and ASTM stability for both the conventional and partially briquetted charges (r of 0.87 and 0.92 respectively) suggesting that the lower stabilities of cokes made at higher flue temperatures might be attributed to the smaller size of the coke. Figure 4 shows the decrease of ASTM stability and coke strength as coke oven productivity was increased. Thus increased coke oven productivity is limited by the deterioration of coke strength.

Linear regression analyses for data in Table 3 has shown that ASTM coke stability from this industrial blend could be predicted for both conventional and partially briquetted charges by the equation:

ASTM STAB = -13.72 + 0.116BD - 0.019FT, r = 0.97, SE = 0.73, F = 89, where BD is the bulk density of the charge.

ASTM hardness values behaved quite differently and improved with increased flue temperatures and coke oven productivity. Partial briquetting of the charge gave another 3 unit improvement to ASTM coke hardness. Thus, both partial briquetting and carbonizing at faster coking rates improved this coke quality parameter.

Results from the Japanese industrial standard (JIS) tumbler test in Table 3 indicated partial briquetting of this industrial blend improved coke

quality but regression analyses showed no significant relationship between the DI_{15}^{30} or DI_{15}^{150} and oven productivity.

Table 4 and Fig. 5 confirm results found in earlier studies that partial briquetting of coke oven charges improved cokes' strength after reaction (CSR); these cokes also showed a slight decrease in their reactivities (RP) compared to conventionally made cokes (10). As coke oven productivity was increased by increasing flue temperatures the coke strength after reaction and coke reactivity also improved.

For all coke quality parameters, only the ASTM stability factor became poorer with increased heating rates and increased oven productivity; the stability however, is the major coke quality parameter used in North America. If the two ASTM stability relationships in Fig. 4 are made equal and for a base case the oven productivity of a conventional charge is set at 36.9 kg/m_3h (based on 750 kg/m^3 bulk density with 73.8% coke yield for a 15 h coking time to 900°C), then solving the equations shows oven productivity can be increased to 52.3 kg/m^3h or by a factor of about 40% by using partially briquetted charges. Thus by increasing flue temperatures and partially briquetting coke oven charges, results from the 460-mm test oven would indicate that coke productivity can be increased substantially before coke stability or any other coke quality parameter deteriorated below that for the conventional charge.

Coking pressures in 460-mm oven

The test conditions used in the 460-mm oven are designed to simulate normal industrial practise and hence yield cokes of quality typical of that produced industrially. The conditions do not provide a high enough bulk density or a fast enough coking rate to represent the exceptional conditions that can exist under extreme industrial operations. Results would indicate however, partially briquetted charges increase coke oven wall pressures but not to excessive levels (14 kPa) at the conditions used. The more extreme coking conditions used in the smaller 310-mm and Koppers ovens better represent the coking pressures that might result during industrial operation.

Studies in the Koppers test oven

Four flue temperatures of about 1010, 1075, 1115, and 1175°C were used to produce coke at different heating rates for the conventionally and partially briquetted industrial blend. Results are listed in Table 5. Carbonization times to 900°C were much shorter than for the 460-mm oven, varying from about 7 to 9 hours for the conventional charges to about 8 to 10 hours for the partially briquetted charge. Oven productivities to 900°C for partially briquetted charges were about 2% less (on average) than for the conventional charge.

Coke quality results were similar to those found in the 460-mm oven. Mean coke size decreased with increased flue temperatures and coking rates were generally smaller for partially briquetted charges. ASTM stability and hardness values improved by partially briquetting the oven charges. Increasing coke oven productivity by raising flue temperatures improved hardness values but stability values became poorer as shown in Fig. 6.

The narrower width of the Koppers oven resulted in faster coking rates than in the 460-mm oven. The tests made at the higher flue temperatures and higher bulk densities in the Koppers oven are considered more representative of the extreme localized conditions that might occur industrially. The maximum wall pressures from this test oven are therefore considered to be representative of the maximum pressures that may result industrially. Figure 7 shows a relationship found between the oven wall pressure and coke oven productivity for partially briquetted charges; a poorer relationship was found for conventional charges but wall pressures were considerably less than for 30% partially briquetted charges. The wall pressure limit of 14 kPa, considered safe for industrial practice, was exceeded with partially briquetted charges carbonized at the two highest flue temperatures. Figure 7 shows the limiting productivity for safe battery operation is about 69 kg/m^{3}h representing a coking rate in the Koppers oven of about 36 mm/h to 900°C.

CARBOLITE AND 310-MM OVEN

These ovens have silicon carbide tiles and therefore use programmed electrical heating. Conventional and partially briquetted tests were run in these ovens for comparative purposes. The Carbolite oven has comparable width to the 460-mm wide Ottawa oven and Table 6 gives results from conventional and

partially briquetted charging of the industrial blend showing higher ASTM stabilities and hardness for this oven than for the 460-mm oven at similar coking times, Table 3, presumably caused by the lower moisture and higher coal bulk density. ASTM stability and hardness improved upon partial briquetting the charge but the wall pressure of 14.1 kPa just exceeded the safe limit for industrial practise.

The 310-mm oven is similar in width to the Koppers oven and the industrial blend was carbonized conventionally and partially briquetted using a fast and slow coking rate. The slower rate was achieved by having the initial flue temperature at 815°C rather than the standard 900°C and then programming the temperature at the standard rate of 19°C/h. Partial briquetting improved ASTM stabilities, hardnesses, and JIS values as was found for the other test ovens. Faster heating rates caused ASTM stability and mean coke size to decrease while the hardness value improved. The maximum coking pressure for partially briquetted charges was 13.7 kPa (average of duplicate tests) at the slower coking rate but 16.0 kPa at the faster coking rate.

COMPARISON OF COKE QUALITY FROM CONVENTIONAL AND PARTIALLY BRIQUETTED CHARGES AT DIFFERENT COKING RATES FOR THE FOUR CANMET TEST OVENS

When results of coke quality were plotted against coke oven productivities for all four CANMET test ovens, discontinuities were observed in the curves. Plots of coke quality parameters against coking rate (oven width divided by coking time to 900°C) gave better relationships.

Figure 8 shows very good relationships were found between mean coke size (MCS) and the coking rate for the four CANMET ovens. The consistently smaller size of coke produced by partial briquetting in all test ovens cannot be attributed to the higher coal bulk density for these charges because the relationships shown in Fig. 8 are good for all ovens which were charged at different moistures and hence contained coal at different bulk densities. (The coking rate is dependent on the coal bulk density in an oven, with higher bulk densities causing slower coking rates). The smaller size of the partially briquetted coke must therefore be attributed to the finer pulverization of the briquetted coal, the addition of pitch to the briquets or to the physical presence of briquets in the blend.

Figure 9 shows relationships between coking rates and the ASTM stability or hardness values for all CANMET test ovens. (Relationships are not as reliable as found for mean coke size and the two test results from the Carbolite oven appear to be outliers). The results do show however that partial briquetting does improve ASTM hardness and stability but the improvements to the latter appear to decrease as coking rates are increased. If industrial coking rates to 900°C are presently 30 mm/h (about 15 h coking time to 900°C in a 460-mm oven) then from Fig. 9, coking rates can be increased to 34.8 mm/h, a 16% increase in coking rate, before ASTM stability drops below the base level. These figures translate to a productivity increase from 36.2 kg/m^3h for conventional charges to 43.9 kg/m^3h for partially briquetted charges, a 21% increase in productivity, based on average coal bulk densities and yields obtained for each type of charge.

INDUSTRIAL IMPLICATIONS FROM COKING PRESSURES OF CONVENTIONAL AND PARTIALLY BRIQUETTED CHARGES COKED IN CANMET'S FOUR MOVEABLE WALL PILOT COKE OVENS

CANMET's 460-mm wide test oven which is operated at heating rates and coal bulk densities typical of industrial practice gave much lower wall pressures than the 3 other CANMET ovens which have faster coking rates and use higher coal bulk densities.

In 1960, a paper was published reviewing several investigations into the relationship between wall pressures as measured in test ovens and safe operating limits for commercial coke oven batteries that would ensure no wall damage resulted from charging high pressure coal blends (16). The review indicated there was general agreement among cokemakers that a pressure limit of about 14 kPa (2 psi) in a moveable wall test oven was reasonable for use in classifying blends for safety in commercial operation. However, there was a wide divergence of opinion as to procedures to be followed when obtaining test oven data. One school of thought, typified by the Koppers Company method, suggested that wall pressures of 10.5 to 14 kPa should not be exceeded when operating test ovens under procedures representing maximums of both carbonization rate and bulk density. Others indicated that the 14 kPa limit should apply when test ovens are operated at in-plant bulk densities but at varied carbonization rates (16). If the method of the Koppers Company (coal moistures less than 1%, bulk densities greater than 832 kg/m^3, and flue temper-

atures of 1343°C) is applied to this investigation then extrapolation of data in Fig. 7 shows that the Canadian industrial blend used in this investigation should never be charged to industrial batteries, either partially briquetted or conventionally.

If the less conservative criteria of measuring the test oven wall pressures at the operating conditions of a typical industrial battery is used then results from CANMET's 4 moveable wall test ovens suggest wall pressures will not be excessive even for partially briquetted charges coked at the increased productivity rate of 43.9 kg/m^3h. A linear regression analysis to predict wall pressures from coal bulk density and coke oven productivity from all data in this study gave the following solution:

$$\text{Wall pressure} = 0.162 \times (\text{oven prod}) + 0.079 \times BD - 66.01$$

$$r = 0.89,\ F = 63,\ SE = 2.5,\ N = 34$$

Thus for oven productivities of 43.9 kg/m^3h the regression equation indicates the most probable minimum coal bulk density for our industrial blend that would be expected to cause excessive coking pressures would be 910 kg/m_2. To have 95% confidence that this coal would not have coking pressures that exceed 14 kPa, the target wall pressure should be 9 kPa (14-2SE); thus coal bulk density should not exceed 850 kg/m^3 if a productivity rate of 43.9 kg/m^3h is used. (For 99.7% confidence a bulk density of 830 kg/m^3 should not be exceeded with partially briquetted charges).

To ensure that coking pressures are not excessive when carbonizing partially briquetted charges at increased coking rates, work at CANMET has shown that high inert coking coals or non-coking materials such as petroleum coke will reduce oven wall pressures when added to partially briquetted charges without any deterioration to coke quality (10,17). Future work should be done to investigate the influence of high inert blend components on coke oven wall and gas pressures for partially briquetted industrial charges carbonized at accelerated coking rates.

CONCLUSIONS

Today cokemakers operating new six metre batteries generally apply a more conservative approach as to the maximum permissible wall pressures in their ovens than cokemakers operating the older smaller batteries. Each coke plant sets its own criterion for permissible wall pressure depending on oven size and wall construction. In some plants, the wall pressures measured in this study for the partially briquetted charges at the accelerated coking rate may be deemed excessive; by some criteria the pressures from the conventional charges may be considered excessive. In other coking plants, the wall pressures obtained from this study may be considered completely acceptable. Further work in this area is warranted and CANMET is currently undertaking studies to relate gas pressures in industrial coke ovens to that in test ovens (17).

This study has shown that coke oven productivity can be increased up to 20% without any deterioration to coke quality by partially briquetting 30% of the coal charged to the coke oven. Benefits from the increased coking rates will include improved ASTM hardness, coke strength after reaction, and coke reactivities.

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Table 1 - Properties of industrial coal blend

Petrography	
$\bar{R}o$ (%)	1.11
Vitrinite	68.0%
Exinite	10.0%
Semi-fusinite	9.7%
Fusinite	2.0%
Mineral matter	3.6%
Rheology	
FSI	7.5
Maximum Giesler fluidity (ddpm)	795
Total dilation (C+D)	64%
Proximate analysis (d.b)	
Ash	6.7%
VM	28.9%

Table 2 - Outline of CANMET's four pilot-scale coke ovens

Oven designation:	310-mm	460-mm	Koppers	Carbolite
Design basis	Eastern Coal Assoc	Rebuilt 1976	Koppers	Carbolite
Location:	Ottawa	Ottawa	Edmonton	Edmonton
Date installed:	1971	1976	1973	1979
Operating 1979:	Yes	Yes	Yes	Yes
Oven Construction:				
Moveable wall	Yes	Yes	Yes	Yes
Coking chamber dimensions (width x length x height)mm	318 x 991 x 914	475 x 914 x 914	12.0	460 x 913 x 838
Coking chamber refractories	Silicon carbide	High density Silica	Alcor	Silicon carbide
Heating method	Glow bars	Glow bars	Natural gas	Glow bars
Standard Oven Test Conditions:				
Charge weight; lbs	500	800	450	750 - 800
Charge pulverization; % - 3 mm	80 ± 5	80 ± 5	80 ± 5	80 ± 5
Target charge moisture; %	3.0	6.0	3.0	3.5
Resulting charge oven dry bulk density; kg/m	816 ± 16	744 ± 16	816 ± 16	800 ± 16
Heat cycle flue temperature control;	900 to 1070°C at 19.44°C/h	constant 1125°C	constant 1177°C	875 to 1130 15°C/h
Charge push method	0.5 h after C_T = 1010°C	0.5 h after C_T = 1000°C	0.5 h after C_T = 1010°C	3 h after C_T = 950°C
Normal push time; h	9	18	18	18
Quench	wet	wet	wet	wet

C_T Charge centre temperature

Table 3 - Partial briquetting studies with an industrial blend at different heating rates - 18" oven

Type of charge	Conventional charges								Partially briquetted charges							
CHARGE PROPERTIES																
Moisture in Charge .....%	6.0	6.0	5.6	6.0	6.0	6.0	5.9	5.7	4.6	4.6	4.6	4.6	4.6	4.6	4.5	4.6
Minus 3 mm .....%	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	81.1	81.1	81.1	81.1	81.1	81.1	81.1	81.1
CARBONIZATION CONDITIONS																
Calc. Charge Dry Bulk Density in Oven ...kg/m^3	770	776	782	771	784	773	782	794	814	818	814	808	813	808	814	820
Fuel Temp Control .....°C	1075	1075	1125	1125	1200	1200	1275	1275	1075	1075	1125	1125	1200	1200	1275	1275
Charge Push (Centre Temp: .....°C	950	950	954	1027	1071	1037	1101	1121	960	954	988	990	1071	1054	1134	1127
CARBONIZATION RESULTS																
Gross Coking Time (at Push).....hr:min	19:45	20:50	19:35	19:00	19:20	17:00	16:50	16:50	21:00	21:10	20:20	20:10	18:30	17:50	17:40	17:45
Final Centre Temp.....°C	950	950	954	1027	1071	1037	1101	1121	960	954	988	993	1071	1054	1134	1127
Time to 900°C Centre Temp.....hr:min	18:30	19:10	18:20	16:45	15:00	14:45	13:40	13:25	19:30	19:45	18:15	17:45	15:30	15:15	14:00	14:10
Time to Max Pressure		14:45	-	4:00		13:00	-	1:00	16:20	16:40	15:20	14:45	13:15	12:45	-	12:15
Max Wall Pressure .....kPa	0.8	1.9	-	3.5	2.4	0.8	-	0.8	4.3	6.9	4.1	-	3.0	2.8	-	6.1
Coke Yield Actual .....%	74.3	74.0	74.2	73.2	73.7	73.3	73.5	74.0	73.5	74.1	74.2	73.7	72.5	73.0	72.5	72.9
Coke Oven Productivity	30.9	29.9	31.5	33.8	38.6	38.4	41.9	43.7	30.6	30.7	33.3	33.6	38.1	38.6	42.2	42.2
SCREEN ANALYSIS OF COKE																
(cum % retained on)																
102 mm sieve	8.3	8.6	10.8	5.9	3.2	3.7	1.1	2.4	9.1	7.4	7.1	6.2	2.8	3.4	1.0	1.0
76 mm sieve	32.8	38.9	34.1	26.6	18.1	18.8	10.8	11.0	34.6	33.5	26.8	24.7	16.0	14.2	7.9	10.0
51 mm sieve	72.0	75.6	72.3	68.2	58.5	55.5	46.5	45.6	72.4	71.9	65.6	64.0	53.2	52.6	42.3	44.5
38 mm sieve	88.1	89.3	87.3	86.3	82.0	79.7	74.8	74.7	88.9	87.3	74.7	85.1	79.4	79.5	72.4	73.2
25 mm sieve	94.9	95.1	94.2	94.8	94.0	93.8	93.4	92.7	95.7	95.0	95.2	95.0	94.6	94.5	93.2	93.8
19 mm sieve	95.9	96.4	95.4	96.0	95.9	95.8	95.8	95.4	96.5	96.4	96.5	96.6	96.4	96.3	96.1	96.6
13 mm sieve	97.1	97.2	96.5	96.9	97.0	96.8	96.9	96.6	97.4	97.1	97.1	97.2	97.0	97.2	97.0	97.2
Percentage -13 mm (breeze).....	2.9	2.8	3.5	3.1	3.0	3.2	3.1	3.4	2.6	2.9	2.9	2.8	3.0	2.8	3.0	2.8
Mean Coke Size .....in	66.0	68.5	66.8	63.0	57.7	56.9	52.1	52.1	67.0	66.0	61.5	61.7	55.6	55.6	50.0	51.3

Table 3 - Cont'd

COKE APPARENT SPECIFIC GRAVITY	0.862	0.862	0.832	0.850	0.848	0.854	0.857	0.867	0.855	0.871	0.868	0.874	0.868	0.865	0.890	0.895
ASTM COKE TUMBLER TEST																
Stability Factor	54.7	56.1	53.7	54.2	54.4	51.9	51.2	53.2	59.7	60.0	59.1	57.1	56.1	57.2	56.3	57.1
Hardness Factor	64.0	65.3	64.2	65.4	66.7	65.7	66.7	67.9	67.6	68.1	68.6	67.4	70.1	69.9	70.4	69.8
JIS COKE TUMBLE TEST																
(cum % retained on)																
30 revs: 15 mm sieve	93.5	93.7	92.6	93.5	93.0	92.5	92.9	92.4	93.9	93.6	94.6	93.8	93.7	94.0	92.7	93.5
150 revs: 15 mm sieve	81.0	80.7	79.9	81.3	80.8	80.4	80.6	80.2	83.3	83.0	84.5	82.9	83.9	83.1	82.4	82.6

Table 4 - Effect of flue temperature and partial briquetting on CSR and coke reactivity

	Conventional Charges			30% Partially Briquetted Charges		
Flue Temp.	Bd	CSR	RP	Bd	CSR	RP
1075°C	48.1	44.7	37.6	50.9	48.9	34.4
1075°C	48.5	43.1	38.4	51.1	48.8	36.7
1125°C	48.9	43.5	35.9	51.2	51.9	33.7
1125°C	48.2	49.4	32.9	50.5	55.2	31.0
1200°C	49.0	47.6	32.3	50.8	49.9	34.1
1200°C	48.3	46.4	35.1	50.5	49.6	35.2
1275°C	48.9	53.0	31.7	50.9	58.0	30.8
1275°C	49.6	50.5	32.2	51.3	59.3	29.6

Bd = bulk density

CSR = strength after reaction

RP = reaction percent from CSR test

Table 5 - Partial briquetting studies with an industrial blend at different heating rates - Koppers oven

Type of charge	Conventional charges							30% briquetted charges						
CHARGE PROPERTIES														
Moisture in Charge .....%	3.8	3.7	3.8	3.2	4.0	3.5	4.2	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Minus 3 mm .....%	76.5	76.5	76.5	76.5	76.5	76.5	76.5	83.6	83.6	83.6	83.6	83.6	83.6	83.6
CARBONIZATION CONDITIONS														
Calc. Charge Dry Bulk Density in Oven ...kg/m^3	830.4	824.0	822.4	828.8	817.6	808.0	822.4	862.4	878.4	872.0	868.8	881.6	881.6	880.0
Fuel Temp Control .....°C	1006	1019	1075	1081	1114	1176	1176	1004	1016	1078	1075	1114	1171	1179
Charge Push (Centre Temp:) .....°C	1010	1010	-	-	-	1010	-	1010	-	1010	-	-	-	-
CARBONIZATION RESULTS														
Gross Coking Time (at Push).....hr:min	12:02	10:51	10:14	9:29	8:39	7:56	8:10	12:53	12:17	10:21	10:35	9:31	8:42	8:51
Final Centre Temp.....°C	1021	1038	1057	1054	1054	1080	1010	1004		1052	1037	1057	1071	1071
Time to 900°C Centre Temp.....hr:min	9:42	9:20	9:16	8:13	7:34	6:59	7:15	10:22	10:07	9:03	9:07	8:25	7:46	7:52
Time to 1000°C Centre Temp .....hr:min	11:21	10:14	9:42	8:53	8:06	7:23	7.37	12:06	11:29	9:45	9:59	8:57	8:09	8:17
Max Wall Pressure .....kPa	8.2	8.8	10.7	6.6	13.7	15.6	12.3	9.5	10.1	14.3	12.9	17.3	18.5	17.0
Coke Yield Actual .....%	71.6	70.9	71.8	71.0	70.8	70.9	71.8	71.2	70.5	70.2	70.7	70.7	71.0	71.1
Coke Oven Productivity .....kg/m^{3}h	61.3	62.6	63.8	71.6	76.5	82.0	81.4	59.2	61.1	67.7	67.4	74.1	80.5	79.5
SCREEN ANALYSIS OF COKE														
(cum % retained on)														
102 mm sieve	3.9	3.1	0.5	0.3	0.4	0.0	0.0	1.1	3.2	0.0	0.0	0.4	0.0	0.0
76 mm sieve	14.3	12.4	6.2	8.1	4.2	2.2	3.3	12.5	15.9	4.6	4.6	4.8	2.9	0.0
51 mm sieve	61.1	58.2	50.0	49.3	44.6	34.5	39.3	55.4	55.9	42.5	49.1	42.2	40.7	36.4
38 mm sieve	83.2	80.2	78.1	74.5	73.6	64.3	65.2	79.9	79.6	75.7	75.2	71.5	67.4	68.9
25 mm sieve	94.0	93.7	92.6	91.9	92.3	89.9	92.3	93.4	93.7	92.9	93.0	92.3	91.8	92.0
19 mm sieve	95.9	95.9	95.3	95.7	95.6	95.1	95.5	96.0	96.5	95.9	95.8	96.0	95.7	96.0
13 mm sieve	97.1	97.0	96.5	97.0	96.8	96.7	96.9	97.2	97.6	97.2	96.9	97.3	97.2	97.3
Percentage -13 mm (breeze).....	2.9	3.0	3.5	3.0	3.2	3.3	3.1	2.8	2.4	2.8	3.1	2.7	2.8	2.7
Mean Coke Size .....mm	57.4	55.9	51.6	51.3	49.5	45.5	47.0	54.9	55.9	49.5	50.6	49.0	47.5	46.2
COKE APPARENT SPECIFIC GRAVITY	0.89	0.88	0.89	0.87	0.87	0.88	0.87	0.91	0.91	0.92	0.92	0.91	0.95	0.90

Table 5 - Cont'd

ASTM COKE TUMBLER TEST														
Stability Factor	53.3	52.6	51.4	50.2	48.8	49.7	49.4	55.6	55.3	53.6	52.3	51.7	49.9	50.5
Hardness Factor	68.1	69.1	69.5	68.8	68.8	69.6	69.3	69.5	69.7	72.5	70.2	72.1	72.3	72.6
JIS COKE TUMBLE TEST														
(cum % retained on)														
30 revs: 15 mm sieve	91.8	92.0	92.2	92.0	92.0	91.2	92.0	93.1	93.1	92.9	92.6	92.3	92.6	92.6
150 revs: 15 mm sieve	80.2	80.4	80.7	80.7	81.8	79.5	81.8	82.5	82.7	82.1	82.2	81.3	81.6	83.5

Table 6 - Partial briquetting studies with an industrial blend in the Carbolite oven

	Conv. charge	30% partially briquetted charge
CHARGE PROPERTIES		
Moisture in Charge .....%	3.3	2.7
Minus 3 mm .....%	76.5	76.5
Other		
CARBONIZATION CONDITIONS		
Calc. Charge Dry Bulk Density in Oven ...kg/m^3	819.2	873.6
Fuel Temp Control .....°C		
Charge Push (Centre Temp:) .....°C	950 + 3h	950 + 3h
CARBONIZATION RESULTS		
Gross Coking Time (at Push).....hr:min	18:41	19:29
Final Centre Temp.....°C	1050	1058
Time to 900°C Centre Temp.....hr:min	15:17	16:06
Max Wall Pressure .....kPa	3.71	14.1
Coke Yield Actual .....%	71.5	71.6
Coke Oven Productivity .....kg/m^{3}h	38.3	38.7
SCREEN ANALYSIS OF COKE		
(cum % retained on)		
102 mm sieve	3.7	2.4
76 mm sieve	16.0	14.1
51 mm sieve	67.7	61.3
38 mm sieve	87.1	85.2
25 mm sieve	94.8	95.3
19 mm sieve	96.2	96.6
13 mm sieve	97.4	97.5
Percentage -13 mm (breeze).....	2.6	2.5
Mean Coke Size .....mm	59.7	57.7

Table 6 - Cont'd

COKE APPARENT SPECIFIC GRAVITY	0.91	0.92
ASTM COKE TUMBLER TEST		
Staoility Factor	56.7	58.9
Hardness Factor	69.4	70.9
JIS COKE TUMBLE TEST		
(cum % retained on)		
30 revs: 15 mm sieve	93.1	93.9
150 revs: 15 mm sieve	82.4	83.0

Table 7 - Partial briquetting studies with an industrial blend in the Ottawa 310-mm wide oven

	Conventional charges				30% Briquetted charges			
CHARGE PROPERTIES								
Moisture in Charge .....%	4.0	3.8	3.8	3.8	3.1	3.1	3.1	3.2
Minus 3 mm .....%								
Other								
CARBONIZATION CONDITIONS								
Calc. Charge Dry Bulk Density in Oven ...kg/m^3	779.2	844.8	800.0	844.8	830.4	846.4	852.8	844.8
Fuel Temp Control .....°C	*900 + 19	900 + 19	815 + 19	815 + 19	900 + 19	900 + 19	815 + 19	815 + 19
Charge Push (Centre Temp:) .....°C								
CARBONIZATION RESULTS								
Gross Coking Time (at Push).....hr:min	9:25	9:45	11:20	11:30	10:10	10:35	12:30	12:15
Final Centre Temp.....°C	-	1050	1010	1010	1043	1054	1037	10:35
Time to 900°C Centre Temp.....hr:min	8:10	8:30	10:10	10:30	9:10	9:20	11:05	10:35
Time to 1000°C Centre Temp .....hr:min								
Max Wall Pressure .....kPa	-	9.9	7.2	9.8	15.0	16.9	15.0	12.3
Coke Yield Actual .....%	74.0	72.7	76.5	73.2	72.9	73.6	72.6	72.1
Coke Oven Productivity .....kg/m^{3}h	70.6	73.3	60.1	58.9	66.1	66.7	55.8	57.6
SCREEN ANALYSIS OF COKE								
(cum % retained on)								
102 mm sieve	0.3	0.5	1.9	2.0	0.0	0.0	0.8	1.4
76 mm sieve	7.6	10.0	16.1	16.1	5.6	5.6	10.9	14.6
51 mm sieve	48.5	49.8	62.2	62.2	43.1	39.7	35.7	60.5
38 mm sieve	76.9	76.9	83.8	83.1	76.9	72.6	82.3	84.8
25 mm sieve	93.1	92.0	93.9	94.1	93.5	93.5	94.8	94.9
19 mm sieve	95.3	94.0	95.7	95.9	95.5	96.0	96.3	96.3
13 mm sieve	96.5	95.2	96.5	97.0	96.6	96.9	97.3	97.2
Percentage -13 mm (breeze).....	3.5	4.8	3.5	3.0	3.4	3.1	2.7	2.8
Mean Coke Size .....mm	51.6	51.6	57.7	57.7	50.0	48.8	54.9	57.2
COKE APPARENT SPECIFIC GRAVITY	0.88	0.91	0.91	0.92	0.90	0.92	0.92	0.90

Table 7 - Cont'd

ASTM COKE TUMBLER TEST								
Stability Factor	52.6	51.8	54.7	55.2	55.6	54.8	57.0	58.2
Hardness Factor	67.6	68.9	66.8	68.1	71.3	70.8	71.2	69.6
JIS COKE TUMBLE TEST								
(cum % retained on)								
30 revs: 15 mm sieve	92.0	92.3	92.2	92.3	92.4	93.1	93.5	94.2
150 revs: 15 mm sieve	80.1	81.0	80.1	81.3	81.3	82.7	82.8	83.6

*Flue programmed to start at 900°C and increase at 19°C/h.

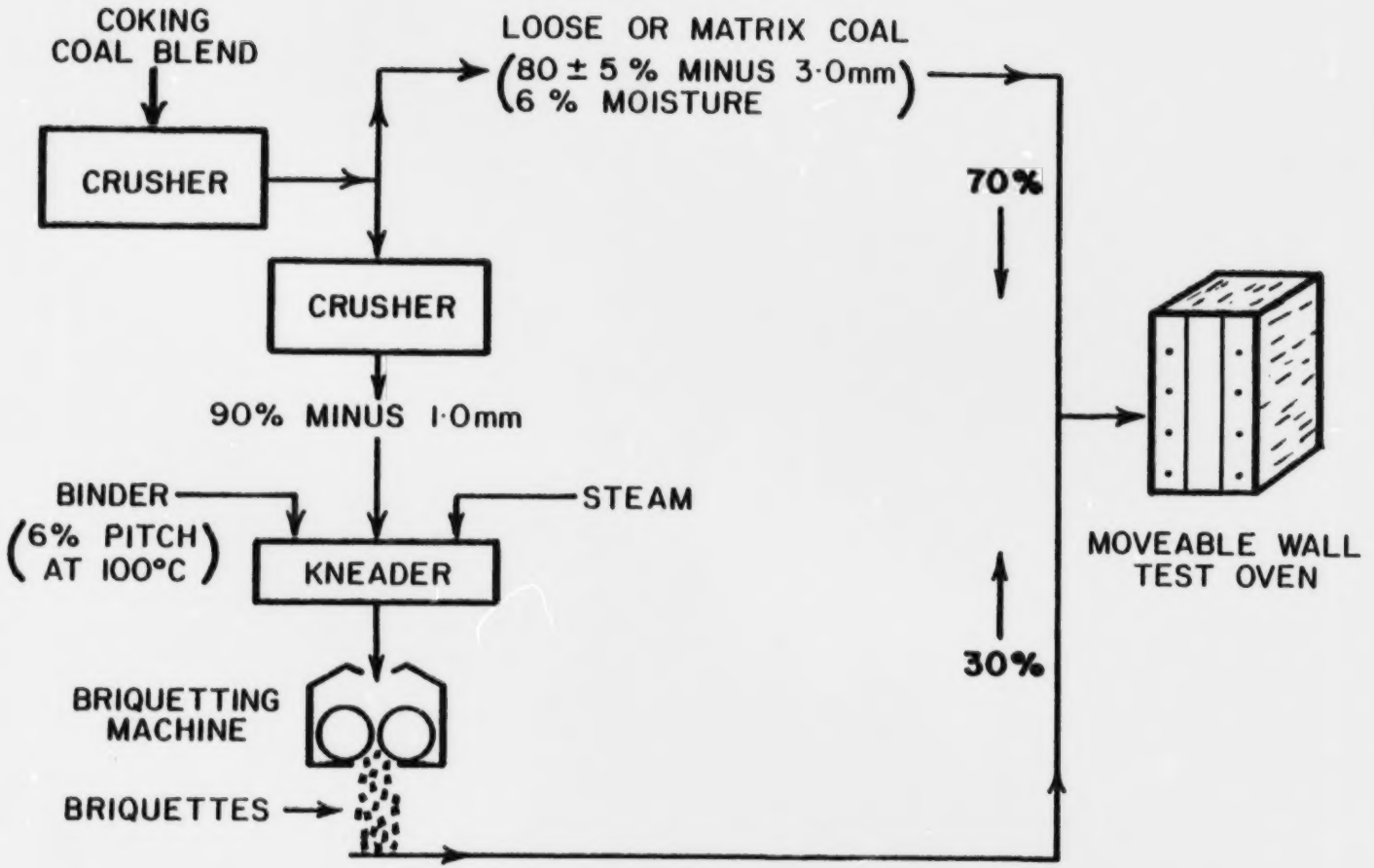

Figure I. FLOW DIAGRAM OF CANMETS PARTIAL BRIQUETTING PROCEDURE

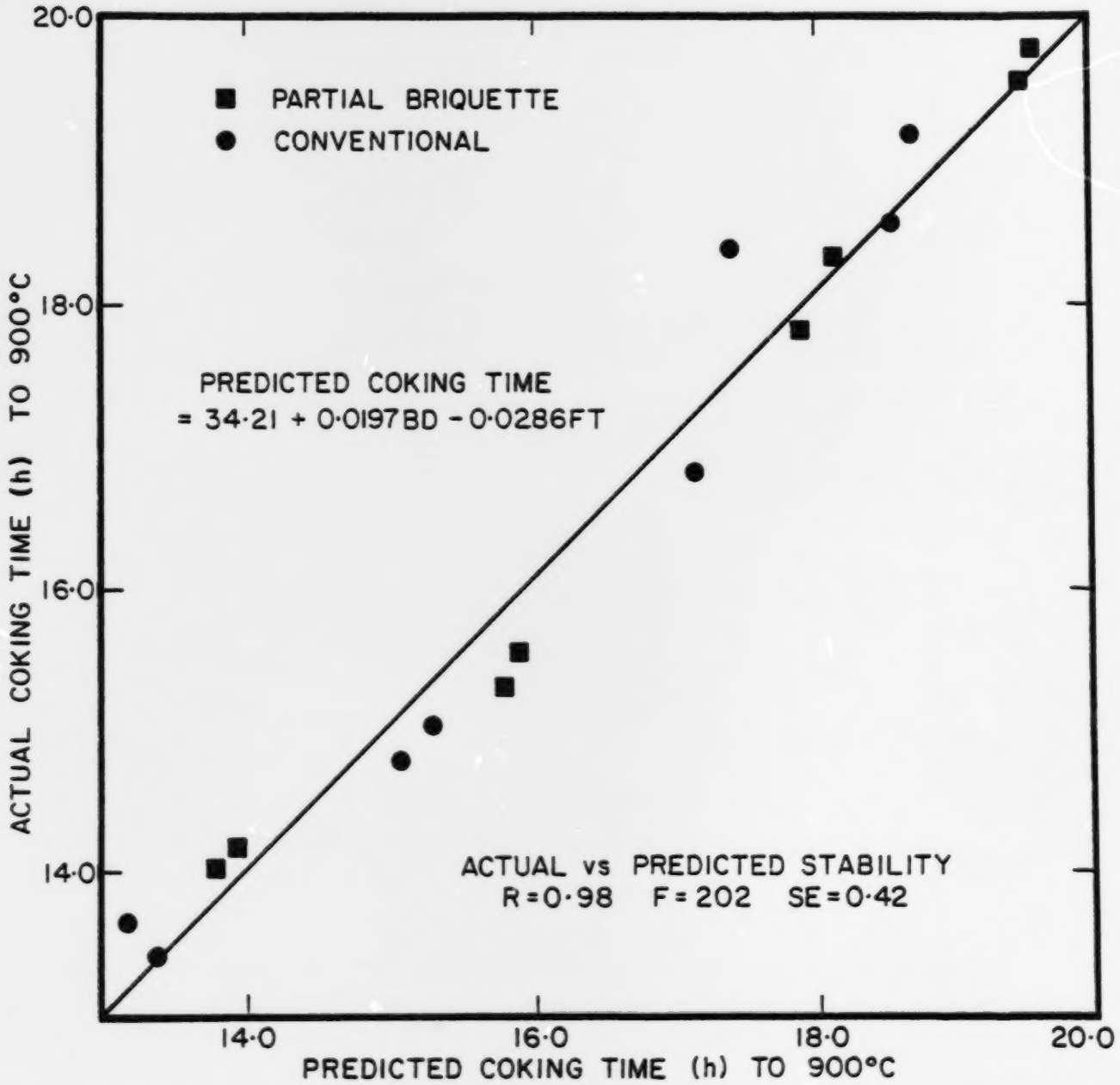

Fig. 2 - Prediction of coking time to 900°C from flue temperature and coal bulk density in 460-mm oven.

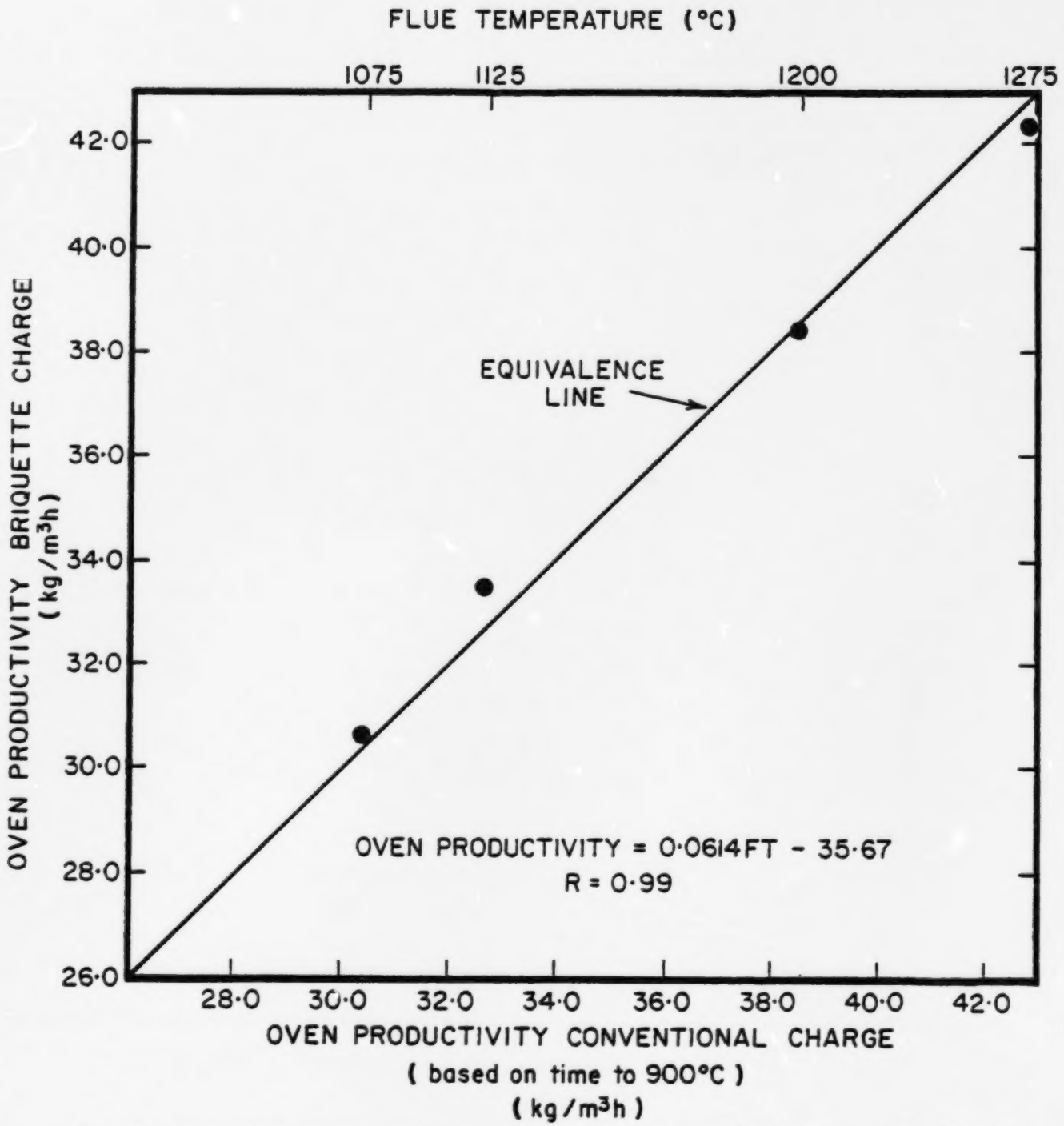

Fig. 3 - Comparison of conventional and partially briquetted coke oven productivities for 460-mm oven

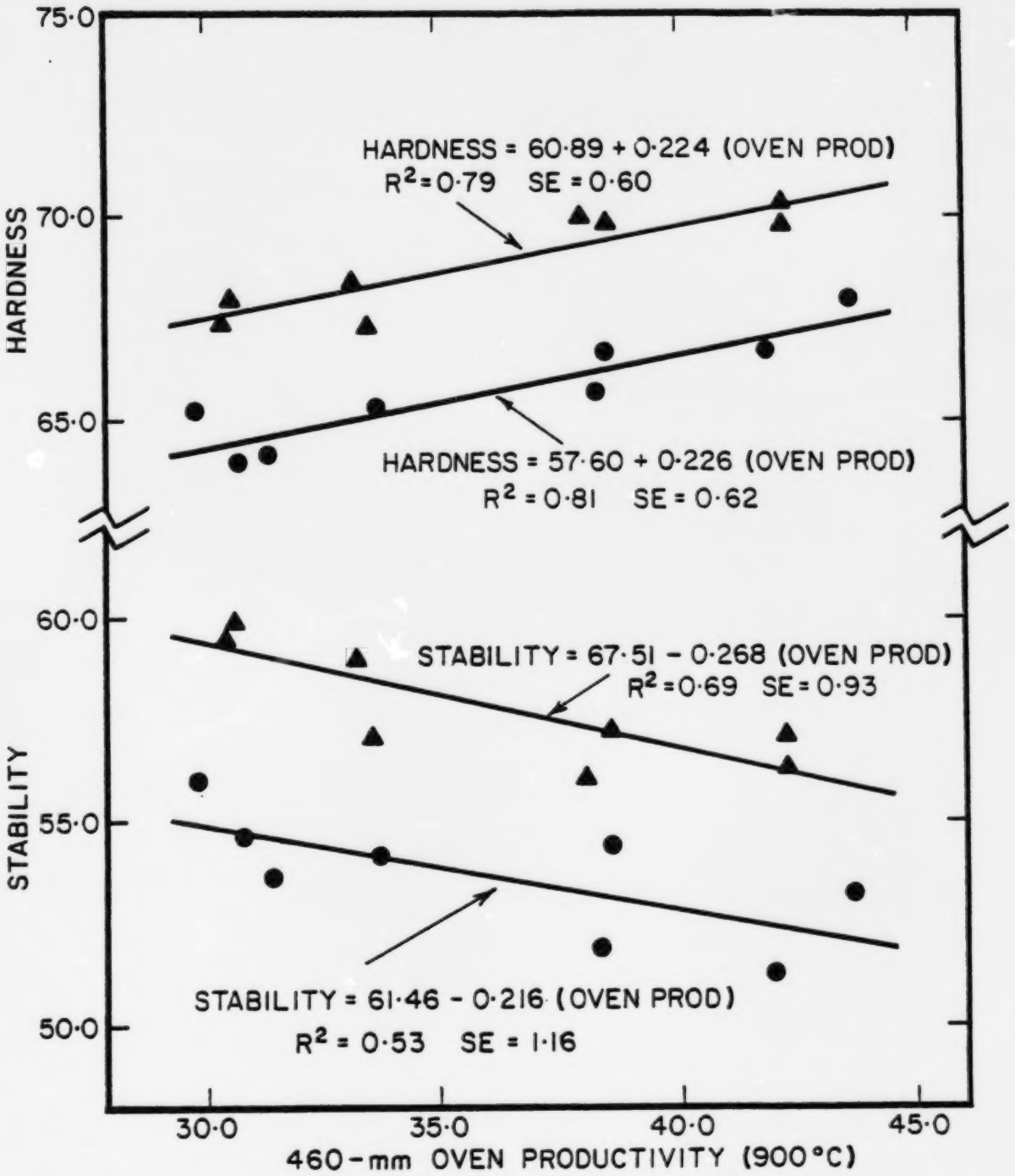

Fig. 4 - Effect of oven productivity on ASTM tumbler indices of coke from 460-mm oven for conventional and partially briquetted charges.

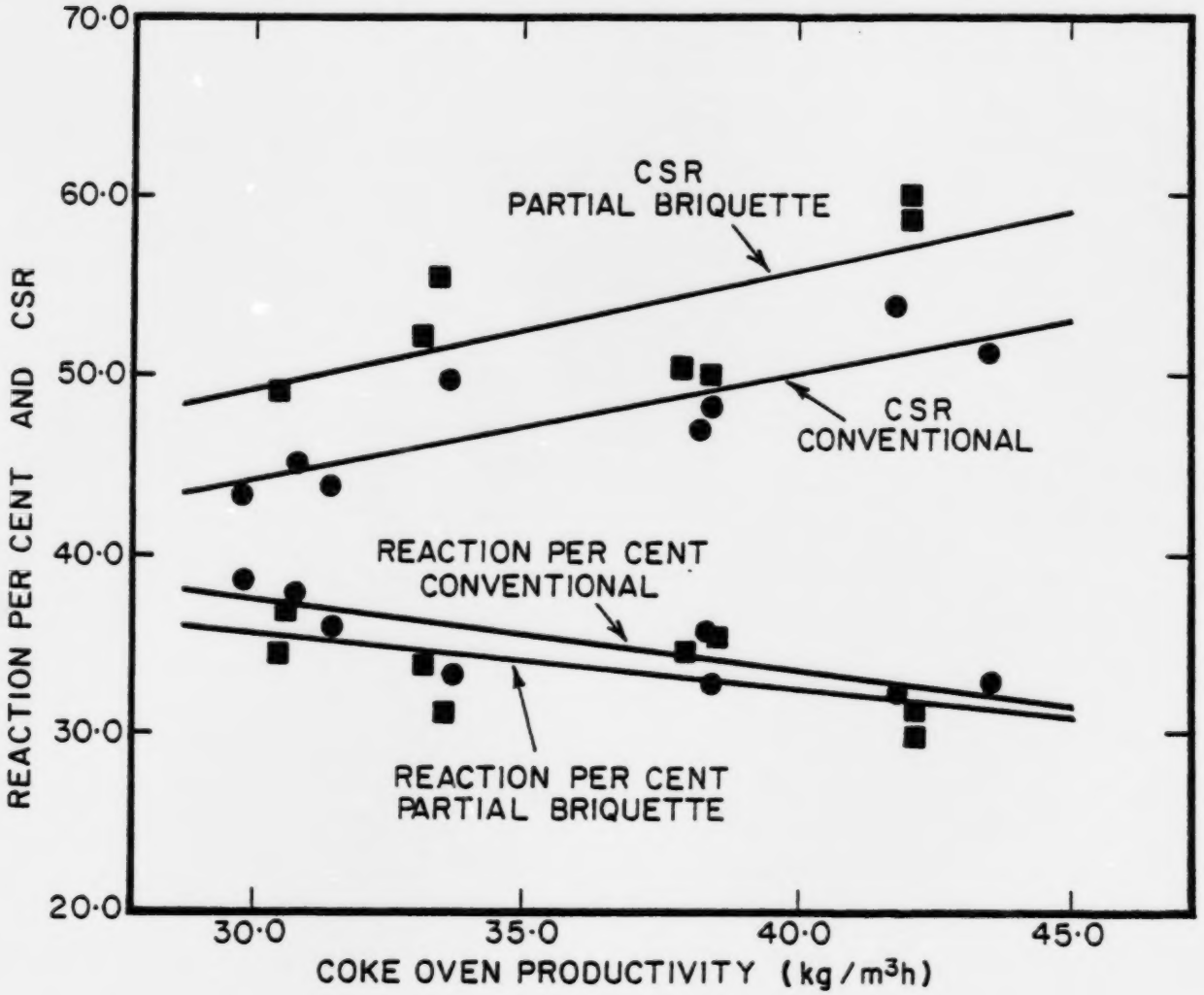

Fig. 5 - Effect of coke oven productivity (460-mm oven) on coke strength after reaction (CSR) and its reaction percent.

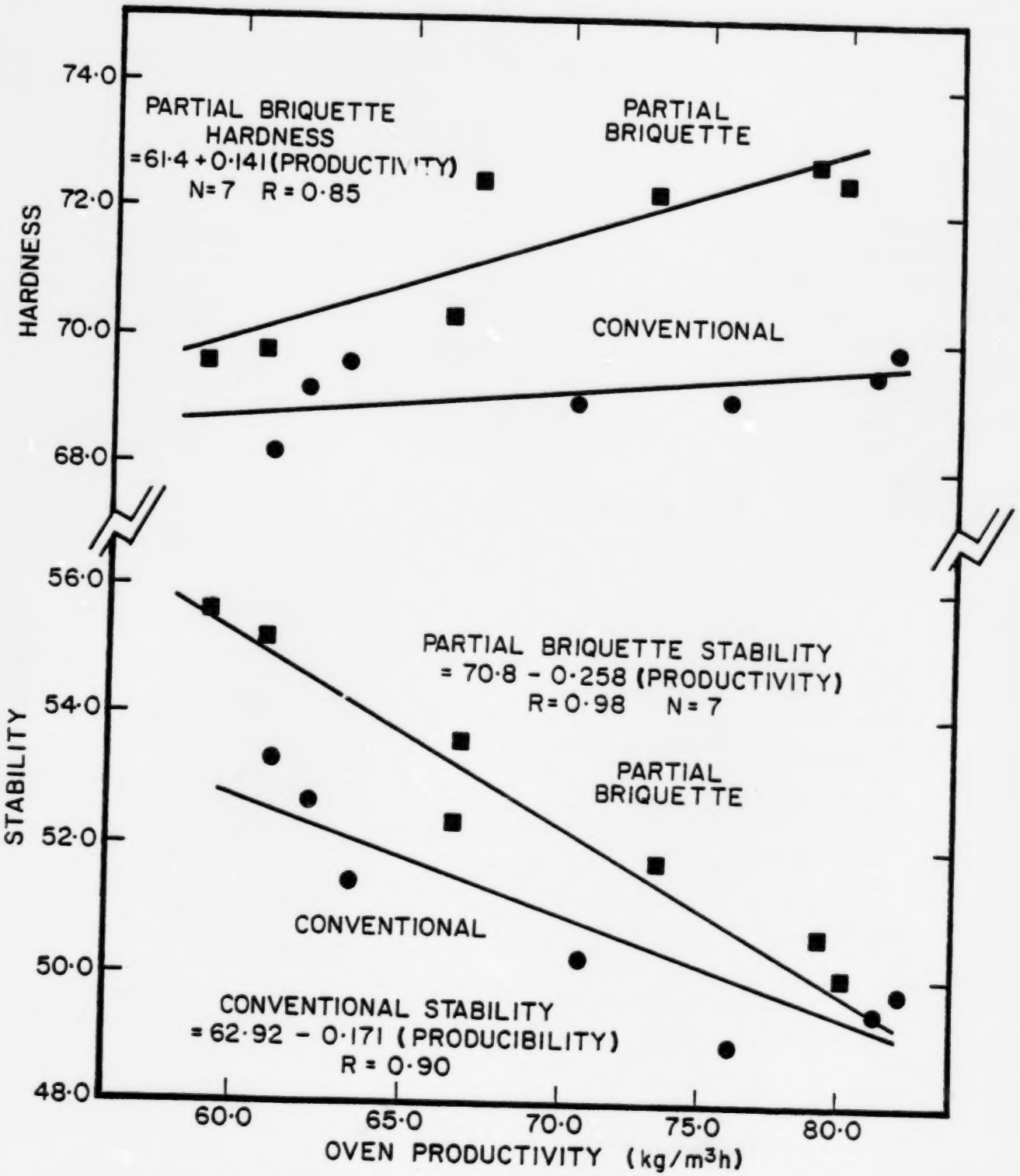

Fig. 6 - Effect of oven productivity on ASTM tumbler indices for conventional and partially briquetted charges in Koppers oven.

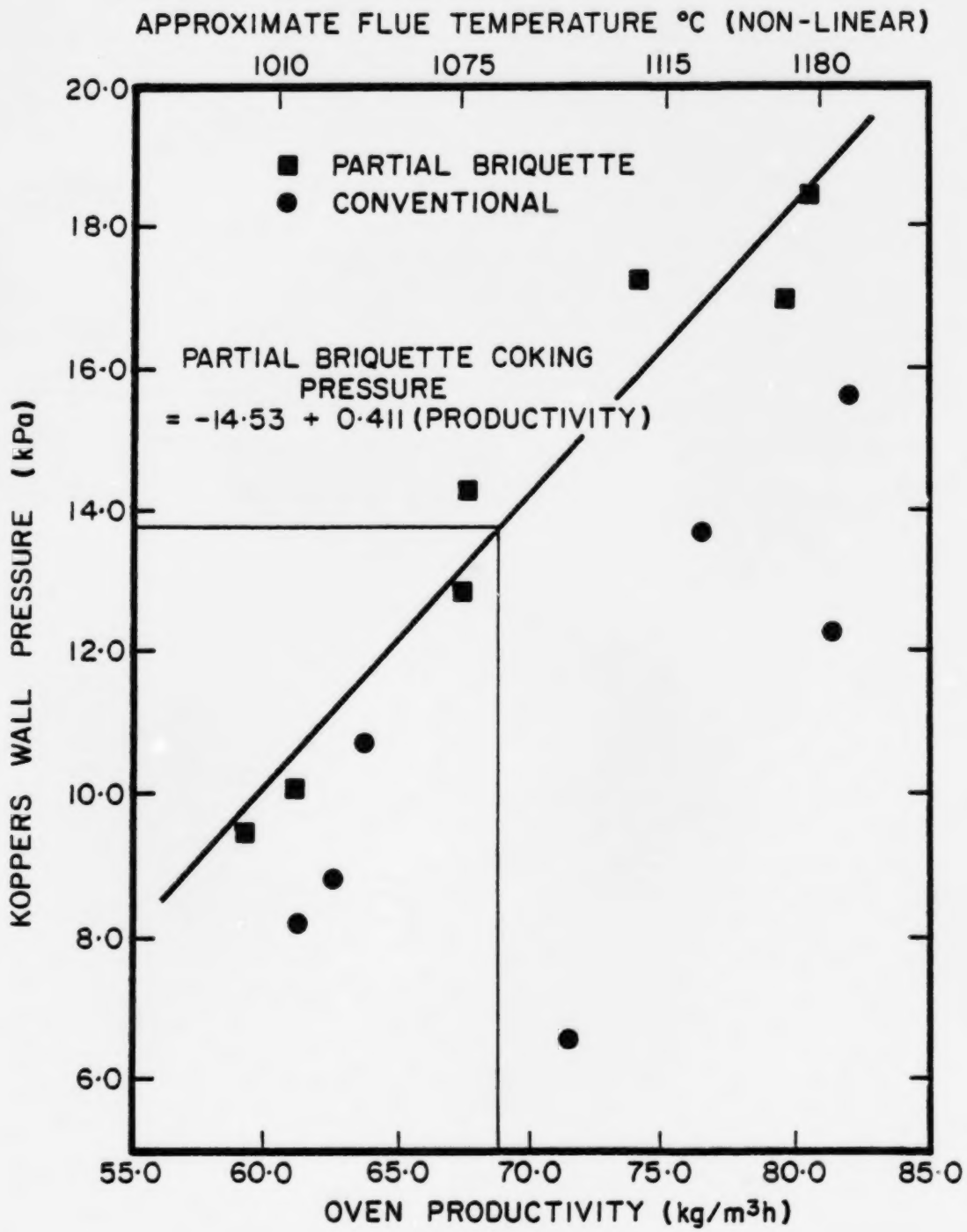

Figure 7. WALL PRESSURE IN KOPPERS OVEN VERSUS OVEN PRODUCTIVITY (based on coking times to 900°C)

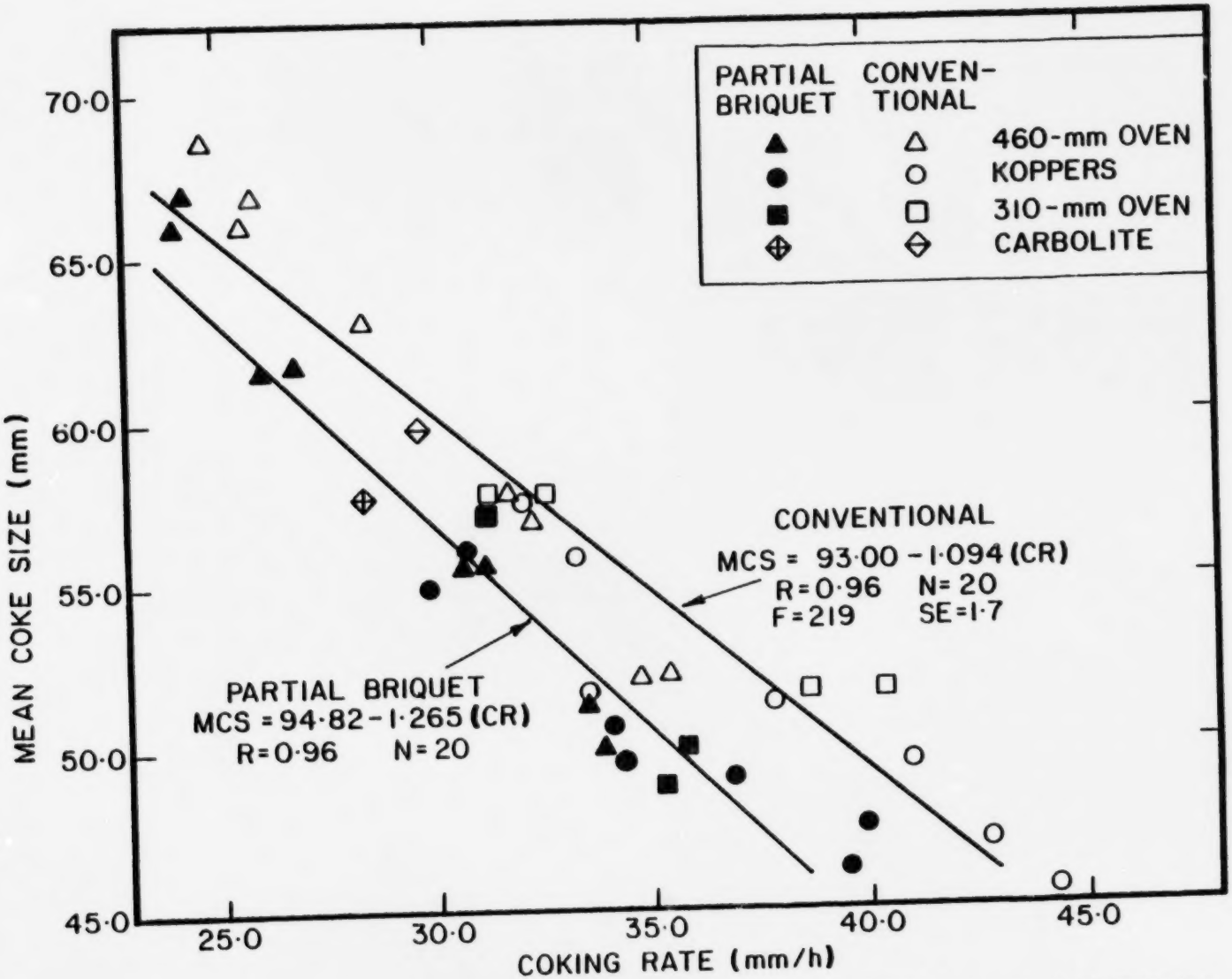

Figure 8. EFFECT OF COKING RATE ON MEAN COKE SIZE OF CONVENTIONAL AND PARTIALLY BRIQUETTED COKE OVEN CHARGES WITH ALL CANMET COKE OVENS.

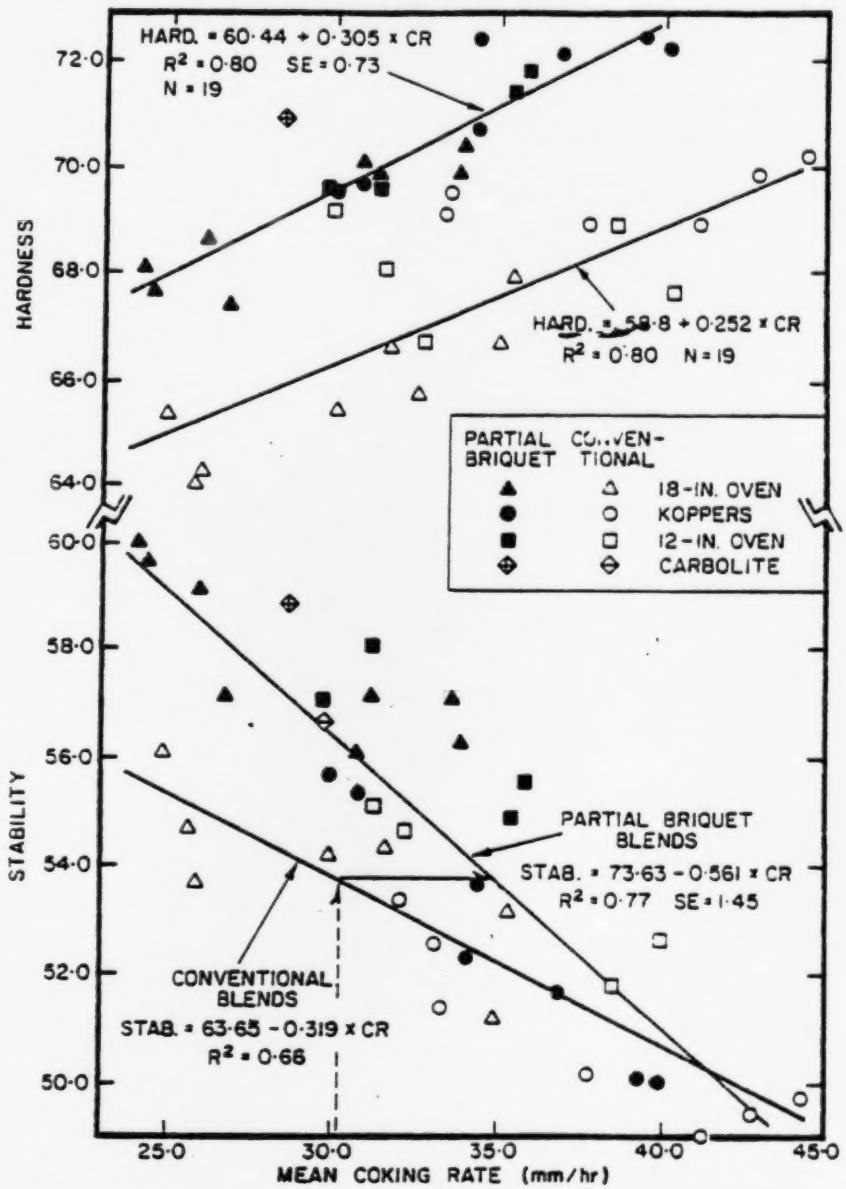

Fig. 9 Effect of coking rate on ASTM tumbler indices for conventional and partially briquetted charges for all CANMET ovens.